SEMICONDUCTOR DEVICES PASSIVATION FILM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part application of pending U.S. patent application serial number 08/949,283 filed on October 21, 1997, entitled "Process for Producing Semiconductor Devices and Semiconductor Devices Produced thereby" which in turn is a continuation-in- part application of U.S. patent application serial number 08/528,123 filed on September 14, 1995, entitled "Process for Producing Semiconductor Devices and Semiconductor Devices Produced thereby", now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates generally to a semiconductor device and a process for producing the same. Particularly, the present invention relates to the structure of a passivation film for insulating and protecting wirings and a technique of forming the passivation film.

In order to stabilize performance of semiconductor devices, a passivation film for insulating and protecting wirings is formed conventionally on the surface of each device.

Generally, the passivation film is an insulating film formed by means of thermal CVD or plasma CVD. Particularly, silicon nitride films formed by means of plasma CVD are frequently employed because of their excellent moisture resistance. However, silicon nitride films are not fully

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resistant to moisture but permit permeation of very small amounts of moisture.

Japanese Unexamined Patent Publication No. 6-53210 discloses a technique of achieving absorption and dispersion of moisture permeating the silicon nitride film by forming a PSG (phospho-silicate glass) film under the silicon nitride film. The publication also discloses forming another silicon nitride film under the PSG film to enhance moisture resistance. However, there still remains the apprehension that the moisture will affect wirings even if moisture is absorbed and dispersed in the PSG film.

It is an objective of the present invention to provide a semiconductor device having a passivation film with excellent moisture resistance, as well as, a process for producing the same.

SUMMARY OF THE INVENTION

Briefly stated, the present invention provides a semiconductor device including a semiconductor substrate, wirings located on the semiconductor substrate, and a passivation film, located on the wirings, including a first insulating film which contains an impurity. The first insulating film is formed from silicon oxide film materials containing over 1% carbon.

The present invention provides a semiconductor device including a semiconductor substrate, wirings located on the semiconductor substrate, and a passivation film, located on the wirings, including a first insulating film which contains an impurity. The first insulating film includes an

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inorganic SOG(Spin-on-Glass).

The present invention provides a semiconductor device including a semiconductor substrate, wirings located on the semiconductor substrate, and a passivation film located on the wirings, including a first insulating film and a second insulating film. The first insulating film contains an impurity and is formed from silicon oxide film materials containing over 1% carbon. The second insulating film is located on at least one of an upper side and a lower side of the first insulating film.

The present invention provides a semiconductor device including a semiconductor substrate, wirings located on the semiconductor substrate, and a passivation film located on the wirings, including a first insulating film and a second insulating film. The first insulating film includes an inorganic SOG(Spin-on-Glass) film containing an impurity. The second insulating film is located on at least one of an upper side and a lower side of the first insulating film.

The present invention provides a method of fabricating a semiconductor device including the steps of: forming wirings on a semiconductor substrate; forming a passivation film including a first insulating film on the wirings; and introducing an impurity into the first insulating film.

Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with the objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments taken in conjunction with the accompanying drawings in which:

Figures 1 through 10 are cross-sectional views showing a process for producing a semiconductor device according to a first embodiment of the present invention;

Figures 11 through 20 are cross-sectional views showing a process for producing a semiconductor device according to a second embodiment of the present invention;

Figures 21 through 25 are characteristic charts for explaining the embodiments of the present invention;

Figure 26 is a graph showing characteristic curves of SOG films; and

Figures 27 and 28 are graphs showing characteristic curves of various types of SOG films.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A process for producing a semiconductor device according to a first embodiment of the invention will be described referring to Figures 1 to 10.

In Step 1 shown in Figure 1, a gate insulating film 2 (film thickness: about 10 nm) and a gate electrode 3 (film

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thickness: about 200 nm) are formed on a [100] p-type (or n-type) single crystal silicon substrate 1. Then, the substrate 1 is doped with an n-type (or p-type) impurity by means of ion implantation utilizing the gate insulating film

5　　2 and gate electrode 3 as a mask to form source and drain regions 4 in self alignment to form an MOS transistor.

Next, in Step 2 shown in Figure 2, a silicon oxide film 5 (film thickness: about 500 nm) is formed over the entire surface of the formed MOS device using a plasma CVD method.

10　　The gas employed in the plasma CVD method is preferably a mixed gas of, for example, monosilane and nitrogen suboxide (SiH. + N.O), monosilane and oxygen (SiH. + O.), or TEOS (tetra-ethoxy-silane) and oxygen (TEOS + O.). The silicon oxide film 5 is formed at a temperature of 300 to 900°C.

15　　In Step 3 shown in Figure 3, an organic SOG (Spin On Glass) film 6 is formed on the silicon oxide film 5. The silicon-containing compound of the organic SOG film 6 has a composition of [CH,Si(OH),] and a film thickness of about 400 nm. Referring to the method of forming the film 6, a

20　　solution of the silicon-containing compound in an alcoholic solvent (e.g., IPA (isopropyl alcohol) + acetone) is first dropped onto the substrate 1, and then the substrate 1 is rotated at about 5400 rpm for about 20 seconds to form a film of the solution on the substrate 1. In this process,

25　　the film 6 is formed to compensate for steps present on the substrate 1. That is, the solution is preferably applied thick in recesses of the substrate 1 and thin at protrusions thereof. Thus, the surface of the alcoholic solution film is planarized.

Next, the thus treated substrate 1 is heat-treated
successively at 100°C for one minute, at 200°C for one
minute, at 300°C for one minute, at 22°C for one minute and
at 300°C for 30 minutes in a nitrogen atmosphere to
5   evaporate the alcoholic solvent and also to promote a
polymerization reaction of the silicon-containing compound,
forming the organic SOG film 6 having a flat surface. The
organic SOG film 6 is an organic insulating film that
contains over 1% carbon.

10   The organic SOG film 6 is then doped with argon ions
(Ar⁺) by means of ion implantation to achieve decomposition
of the organic components, as well as, reduction of the
water and hydroxyl groups contained in the film 6. The
doping treatment is carried out with an acceleration energy
15   of 140 keV and a dose of about 1×10^{15} ions/cm^2. As a
result, the organic SOG film 6 is converted to an SOG film,
hereinafter referred to as the modified SOG film 7
containing only small amounts of water and hydroxyl groups
and no organic component. It should be noted here that the
20   argon ions correspond to the impurity having a kinetic
energy.

In Step 4 shown in Figure 4, a silicon oxide film 8
(film thickness: about 200 nm) is formed on the modified SOG
film 7 using a plasma CVD method. The silicon oxide film 8
25   is formed under the same conditions as the silicon oxide
film 5 is formed. In Step 5 shown in Figure 5, via holes 9
are formed through the films 5, 7 and 8 present on the
source/drain regions 4 by anisotropic etching such as by
employing a mixed gas of carbon tetrafluoride and hydrogen
30   as an etching gas.

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In Step 6 shown in Figure 6, an aluminum film is formed
on the silicon oxide film 8 including the bores of the via
holes 9 by sputtering. The aluminum film is then removed
partly by anisotropic etching until the silicon oxide film 8
5　　is partly exposed to form source and drain electrodes
(source and drain wirings) 10 in a desired pattern.

In Step 7 shown in Figure 7, a silicon oxide film 12
(film thickness: about 200 nm) is formed over the entire
surface of the device. Subsequently, an organic SOG film 13
10　　is formed on the silicon oxide film 12, followed by
implantation of argon ions to the organic SOG film 13 to
form a modified SOG film 14 (film thickness: about 400 nm).
The organic SOG film 13 and the modified SOG film 14 are
preferably formed in the same manner as the organic SOG film
15　　6 and the modified SOG film 7.

Next, a silicon oxide film 15 (film thickness: about
200 to about 400 nm) is formed on the modified SOG film 14.
The silicon oxide films 12 and 15 are preferably formed in
the same manner as the silicon oxide film 5 is formed in
20　　Step 2. The silicon oxide film 12, the modified SOG film 14
and the silicon oxide film 15 comprises a passivation film
16. The passivation film 16 insulates and protects the
device, particularly the source and drain electrodes 10.
The passivation film 16 according to the present invention
25　　has a sandwich structure in which the modified SOG film 14
is sandwiched between the silicon oxide films 12 and 15.
Accordingly, the passivation film 16 has high insulating
properties and high mechanical strength.

Particularly, the insulating effect exhibited by the

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passivation film 16 is enhanced by the presence of the
silicon oxide film 12. Furthermore, the silicon oxide film
12 exhibits better adhesion to wirings than to the modified
SOG film 14, so that adhesion of the passivation film as a

5　　　whole is improved. The presence of the silicon oxide film
15 enhances the moisture sealing effect of the passivation
film 16. Further, the modified SOG film 14 has excellent
step-covering properties, so that even narrow gaps between
the wirings are fully embedded with the film 14. In

10　　　addition, the modified SOG film 14 has excellent evenness,
it facilitates formation of the silicon oxide film 15. The
silicon oxide films 12 and 15 also have good step-covering
properties, so that narrow gaps present between the wirings
are covered with the film 12 or 15 easily.

15　　　Since the modified SOG film 14 hardly contains moisture
and hydroxyl groups and contains no organic component, the
modified SOG film 14 alone may constitute the passivation
film 16, as shown in Figure 8. In this case, the procedures
of forming the silicon oxide films 12 and 15 are omitted.

20　　　In the case where the organic SOG film 13 fails to be
fully modified by ion implantation or the silicon oxide film
12 or 15 is desired to be omitted, the passivation film 16
may be formed having no silicon oxide film 15, as shown in
Figure 9, or having no silicon oxide film 12, as shown in

25　　　Figure 10.

The first embodiment employs the sandwich structure in
which the modified SOG film 7 is sandwiched between the
silicon oxide films 5 and 8, which enhances the insulating
properties and mechanical strength of the layer insulating

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film 11 as a whole. Further, since the modified SOG film 7
contains no organic component, the etching treatment for
forming the via holes 9 is carried out in a mixed gas
atmosphere of carbon tetrafluoride and hydrogen.
5   Accordingly, even if a photoresist is employed as an etching
mask, the photoresist is not attacked, nor is the modified
SOG film 7 masked with the photoresist etched. Thus, fine
via holes 9 are formed accurately.

Since the modified SOG film 7 contains no organic
10   component, the modified SOG film 7 and the silicon oxide
films 5 and 8 may be etched at the same etching rate. In
addition, the modified SOG film 7 undergoes no shrinkage
during ashing treatment for removing the photoresist etching
mask. Accordingly, the modified SOG film 7 undergoes
15   neither cracking nor formation of recesses when the via
holes 9 are formed. Thus, the aluminum film can be embedded
fully in the via holes 9 to secure excellent contact between
the source and drain electrodes 10 and the source and drain
regions 4 respectively.

20   Since the modified SOG film 7 contains very small
amounts of moisture and hydroxyl groups and no organic
component, either the silicon oxide film 5 or the silicon
oxide film 8 or both may be omitted to allow the layer
insulating film 11 to have a single layer structure
25   consisting of the modified SOG film 7 only or a two-layer
structure consisting of the modified SOG film 7 and the
silicon oxide film 5 or 8.

Next, a process for producing a semiconductor device
according to a second embodiment of the invention will be

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described referring to Figures 11 to 20. It should be noted
here that like and same components as in the first
embodiment are affixed with the same reference numbers
respectively and detailed description of them will be

5　　　omitted.

In Step (1) shown in Figure 11, on a p-type (or n-type)
single crystal silicon substrate 1 are formed a gate
insulating film 2, a gate electrode 3 and source and drain
regions 4 to complete an MOS transistor. An interlayer

10　　insulating film 21 is then formed over the entire surface of
the device, and contact holes 22 are defined through the
interlayer insulating film 21 over the source and drain
regions 4. Subsequently, an aluminum film is deposited by
means of sputtering over the entire surface of the device

15　　including the bores of the contact holes 22, and the
aluminum film is subjected to anisotropic etching to form
source and drain electrodes (source and drain wiring) 10
having desired patterns.

In Step (2) shown in Figure 12, a silicon oxide film 5

20　　is formed over the entire surface of the device. In Step
(3) shown in Figure 13, an organic SOG film 6 is formed on
the silicon oxide film 5, followed by ion implantation to
convert the organic SOG film 6 into a modified SOG film 7.

In Step (4) shown in Figure 14, a silicon oxide film 8

25　　is formed on the modified SOG film 7. The films 5, 7, 8
form a layer insulating film 11. In Step (5) shown in
Figure 15, the device is subjected to anisotropic etching,
preferably using a mixed gas of carbon tetrafluoride and
hydrogen as an etching gas to form via holes 9 through the

films 5, 7 and 8 present on the source and drain areas 4.
In Step (6) shown in Figure 16, aluminum is deposited over
the entire surface of the device including the bores of the
via holes 9 by means of sputtering, and the resulting
5　aluminum film is then subjected to anisotropic etching to
form wirings 23 in a desired pattern.

As described above, according to the second embodiment,
the wirings 23 are formed on the source and drain wirings 10
via the layer insulating film 11.　In this case again, the
10　same actions and effects as in the first embodiment can be
exhibited without affecting the MOS transistor and source
and drain wirings 10.

In Step (7) shown in Figure 17, a passivation film 16
having a sandwich structure, comprising a silicon oxide film
15　12, a modified SOG film 14 and a silicon oxide film 15, is
formed over the entire surface of the device in the same
manner as in step 7 of the first embodiment.　The
passivation film 16 may have a single layer structure
consisting of the modified SOG film 14 only (see Figure 18)
20　or a two-layer structure consisting of the silicon oxide
film 12 and the modified SOG film 14 (see Figure 19) or of
the silicon oxide film 15 and the modified SOG film 14 (see
Figure 20), like in the first embodiment, shown in Figures 8
to 10.

25　Figures 21 and 22 show results of various tests carried
out employing a test device fabricated by forming an
interlayer insulating film consisting of a silicon oxide
film 8/an organic SOG film 6 (modified SOG film 7)/a silicon
oxide film 5 on an NMOS transistor as shown in the first and

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second embodiments.

Figure 21 shows drain voltage dependency of the hot
carrier life in an NMOS transistor. The hot carrier life
referred to here means the time elapsed until the mutual
5　conductance Gm is deteriorated to a certain level and is a
parameter showing the life of transistor. As shown in
Figure 21, the transistor employing a modified SOG film 7,
particularly with the acceleration energy of 140 keV, has a
hot carrier life of about twice that of a transistor
10　employing an unimplanted organic SOG film.

Figures 22 and 23 show threshold values Vt measured
before and after an acceleration test, respectively. In the
acceleration test, a voltage of 5 V is continuously applied
to the transistor of the test device at a temperature of
15　200°C for 2 hours. Figure 22 shows the threshold value Vt
measured before the acceleration test; while Figure 23
shows amount of change in the threshold value Vt after the
acceleration test. As shown in Figure 22, before the
acceleration test, both the transistor having the
20　unimplanted organic SOG film and the transistor having the
modified SOG film 7 showed no substantial difference in
their threshold values.

However, as shown in Figure 23, in the case where the
unimplanted organic SOG film is employed, the threshold
25　value Vt changes greatly after the test. On the other hand,
in the case where the modified SOG film 7 (particularly with
an acceleration energy of 140 keV) is employed, there is
observed substantially no change in the threshold value Vt
irrespective of the gate length. These results show that

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the threshold value characteristics of the MOS transistor
having the modified SOG film 7 can be stabilized for a long
time period.

Figure 24 shows the amount of change in the mutual
conductance Gm of each transistor determined by measuring it
before and after the acceleration test like in Figure 23.
In the case of a transistor employing an unimplanted organic
SOG film, the Gm changed greatly after the test. On the
other hand, in the case where the modified SOG film 7
(particularly with an acceleration energy of 140 keV) is
employed, there is observed substantially no change in Gm
irrespective of the gate length. These results show that
the Gm of the MOS transistor can be stabilized for a long
time period.

In Figures 21 to 24, in the case where the modified SOG
film 7 formed with an acceleration energy of 20 keV, very
small improving effects are shown compared with the case of
the film formed with an acceleration energy of 140 keV.
This may be because, as shown in Figure 25, the acceleration
energy (implantation energy) and the depth of modification
in the organic SOG film have a substantially positive
correlation, and in the case of the film modified with an
acceleration energy of 20 keV, only the surface layer (about
50 nm) of the organic SOG film 6 is modified.

The unimplanted organic SOG film 6 (13) and the Ar$^+$-
implanted modified SOG film 7 were heat-treated in a
nitrogen atmosphere for 30 minutes and evaluated by means of
TDS (Thermal Desorption Spectroscopy), and the results are
shown in Figure 26. The ion implantation was carried out

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under the following conditions: dose: 1×10^{15} atoms/cm^2;
acceleration energy: 140 keV.

Figure 26 represents a quantity of dissociation of H_2O
(m/e = 18). As shown in Figure 26, it can be understood
that dissociation of H_2O (m/e = 18) is small in the modified
SOG film 7 (14). This indicates that moisture and hydroxyl
groups contained in the organic SOG film 6 (13) are
decreased by forming the modified SOG film 7 (14) as a
result of injecting ions into the organic SOG film 6 (13).

Figure 27 shows a no-treatment organic SOG film 6 (13),
an O_2 plasma organic SOG film 6(13) having undergone oxygen
plasma exposure and a modified (Ar$^+$) SOG film 7(14) left to
stand in a clean room under atmospheric conditions to
examine hygroscopicity of the organic SOG films 6(13) and
the modified SOG film 7(14). The water content of the film
is indicated by the integrated intensity of the absorption
(around 3500 cm^{-1}) attributed to the O-H group in the IR
absorption spectrum by means of an FT-IR method (Fourier
Transform Infrared Spectroscopy). The ion implantation was
carried out under the following conditions:
acceleration energy: 140 keV; dose: 1×10^{16} atoms/cm^2.

It can be understood that, when the organic film 6(13)
was exposed to oxygen plasma, the water content increased
not only immediately after the treatment but also after one
day. Meanwhile, in the modified film 7(14), the water
content did not increase immediately after the treatment,
and the increase in the water content is smaller than the
organic film 6(13) even if it was left to stand under
atmospheric condition in a clean room. Further, the

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modified film 7(14) has hygroscopicity lower than the
organic film 6(13).

The modified SOG film 7(14) and the organic SOG film
6(13) were subjected to a pressure cooker test (PCT) to
examine water permeability of the film 7, and the results
are shown in Figure 28. This test is a humidifying test and
was carried out at 120°C under 2 atm. saturated vapor
pressure atmosphere. Integrated intensity of the absorption
peak (around 3500 cm^{-1}) attributed to the O-H bond in the
organic SOG film 6(13) was determined by means of FT-IR and
plotted with respect to the PCT time.

A sample modified only on the surface of the organic
SOG film 6 by means of ion implantation (Ar$^+$ 20 keV) was
prepared by implanting argon to the organic SOG film 6,
which was compared with an entirely modified organic SOG
film 6 (Ar$^+$ 140 keV) and an unmodified sample (an untreatment
organic SOG film 6(13)) to obtain the following results:

(1) When the unmodified organic SOG film 6 (13) was
subjected to PCT, an absorbance around 3500 cm^{-1} attributed
to O-H showed a steep increase.
(2) In the modified SOG film 7(14), an increase in the
absorbance around 3500 cm^{-1} attributed to O-H is small. The
surface-modified film also showed a similar level of
increase to that of the entirely modified film.

From these results, it can be considered that a layer
which inhibits permeation of water was formed by the ion
implantation.

The present invention is not to be limited to the foregoing embodiments, and similar actions and effects may be exhibited if embodied as follows.

The silicon oxide films 5, 8, 12 and 15 may be formed by a method other than the plasma CVD method, for example, atmospheric CVD method, vacuum CVD method, ECR plasma CVD method, optical pumping CVD method, TEOS-CVD method and PVD method. The gas used in the atmospheric CVD method is preferably monosilane and oxygen ($SiH_4 + O_2$), and the films are formed at a temperature of about 400°C or lower. Meanwhile, the gas used in the vacuum CVD method is preferably monosilane and nitrogen suboxide ($SiH_4 + N_2O$), and the films are formed at a temperature of about 900°C or lower.

The silicon oxide films 5, 8, 12 and 15 may be replaced with other insulating films having high mechanical strength in addition to the property of blocking water and hydroxyl groups, such as silicon nitride film, silicon oxynitride film and silicate glass film. Such insulating film may be formed according to any method including CVD and PVD.

Particularly, when silicon nitride films are employed in place of the silicon oxide film 12 and the silicon oxide film 15, they prevent devices from being affected by alkali metals, since they do not allow permeation of alkali metals such as Na and K. Further, when silicon oxynitride films are employed in place of the silicon oxide film 12 and the silicon oxide film 15, the same actions and effects as those of the silicon nitride film can be exhibited, since the silicon oxynitride films do not allow permeation of alkali

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metals such as Na and K. In addition, the silicon
oxynitride film exhibit high effects of preventing
deterioration of device performance attributed to stress and
deterioration of wiring reliability compared with the

5   silicon nitride films.

The source and drain electrodes 10 and the wiring 23
may be formed using conductive materials other than
aluminum, such as copper, gold, silver, silicide, doped
polysilicones, titanium nitride (TiN) and alloys including

10 tungsten titanium (TiW), or a laminated structure of such
materials.

The modified SOG films 7 and 14 may be subjected to
thermal treatment. In this case, the number of dangling
bonds in the modified SOG films 7 and 14 is reduced, so that

15 not only hygroscopicity but also water permeability of the
film 7 can be reduced further.

Each of the organic SOG films 6 and 13 may be replaced
with an inorganic SOG film, and the inorganic SOG film may
be subjected to ion implantation. In this case, the water

20 and hydroxyl groups contained in the inorganic SOG film can
be reduced.

While argon ion is employed as the ion to be implanted
to the organic SOG films 6 and 13 in the foregoing
embodiments, any ion may be employed as long as it can

25 eventually modify the organic SOG films 6 and 13.
Typically, boron ion, nitrogen ion or phosphorus ion can be
suitably employed as well as argon ion. Boron ion is most
preferable. Further, the following ions are expected to

exhibit sufficient effects:

(1)   Inert gas ions other than argon: helium ion, neon ion, krypton ion, xenon ion and radon ion.   Since the inert gas does not react with the organic SOG film 6(13), there is absolutely no fear of bringing about adverse effects by the ion implantation;

(2)   Simple substance ions of Group IIIb, IVb, Vb, VIb, and VIIb elements excluding boron and nitrogen and ions of compounds containing such elements: particularly, ions of elements including oxygen, aluminum, sulfur, chlorine, gallium, germanium, arsenic, selenium, bromine, antimony, iodine, indium, tin, tellurium, lead and bismuth and compound ions containing such elements.   Of these ions, although the metallic element ions reduce the dielectric constant of the organic SOG film 6(13) after the ion implantation.

(3)   Ions of Group IVa and Va elements and ions of compounds containing such elements: particularly, ions of elements including titanium, vanadium, niobium, hafnium and tantalum and compound ions containing such elements.   Since oxides of Group IVa and Va elements have high dielectric constants, the organic SOG film 6(13) after the ion implantation comes to have a high dielectric constant. However, they present no practical problem except for the cases where interlayer insulating films having particularly high dielectric constants are required; and

(4)   Combinations of the ions described in (1) to (3): In this case, superior effects can be obtained by the

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synergistic effects brought about by the respective ions.

While an ion is implanted to the organic SOG film 6(13) in the foregoing embodiments, the material to be implanted to the film 6 may not be limited to ions but may be atoms, 5 molecules or particles, and they are all referred to as impurities in the present invention.